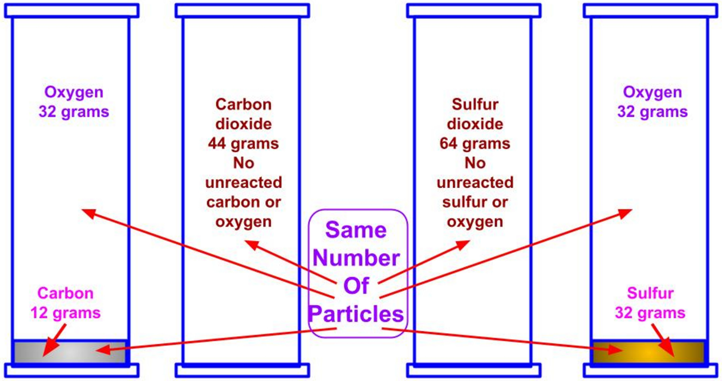
Atoms, molecules and particles of energy

We notice two kinds of changes in the above description of the small particles from which solids, liquids and gases are formed. When pressure is increased carbon dioxide has converted into a liquid. This is one type of change. The properties of a liquid are quite different from that of the gas but once the pressure is reduced the liquid becomes carbon dioxide gas again. Carbon dioxide was formed when vinegar was added to baking soda. We cannot easily get the vinegar and baking soda back from carbon dioxide. This is a second type of change. This is called a chemical reaction. Very few chemical reactions can be reversed to obtain the initial materials called the reactants from the products obtained by the chemical reaction.

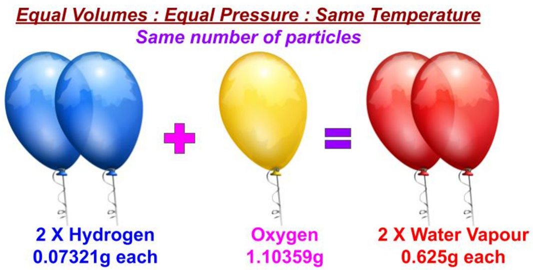
Once we understand the basic nature of a chemical reaction, an obvious question comes to mind. Are all the countless materials we observe in nature formed by the chemical reaction of a few elementary units? If so, how did those get formed? Many philosophers in various cultures discussed these questions. Some named five primordial elements from which everything was made. Others said that the world is made of atoms. But these discussions did not connect to experiments and observations.

Just as Newton at the start of the eighteenth century laid the foundations for physics and moved planetary motion away from astrology, at the end of that century, Dalton laid the foundations for chemistry and separated elements and atoms from philosophy and linked them to experiments. As in the case of physics, precise experiments were responsible for the development of chemistry. The first step was to identify that the sum of the weights of the reactants was equal to that of the reaction products. Thus, the law of conservation of mass became the foundation of chemistry. This in turn led John Dalton to understand that products of chemical reactions were made of elements joining in small simple ratios.



As an example, when 12 grams of carbon are heated with 32 grams of oxygen, exactly 44 grams of carbon dioxide is produced. {Picture left} After the chemical reaction, no excess carbon or oxygen is left. If the initial weights of carbon or oxygen are changed, there will be some unreacted carbon or oxygen left. This immediately shows that the number of small particles in carbon and oxygen used for the reaction has to be equal to the number of particles of carbon dioxide produced. If the same temperature and pressure are equal, experiments show that the volume of oxygen gas used and of the carbon dioxide produced are exactly the same.

Similar experiments helped Amedeo Avogadro confirm that equal volumes of any two gases have equal number of particles, if their temperature and pressure are the same, {Picture right} At the same temperature and pressure, if the weight of a given volume of air is 1.000, the weights of equal volumes of hydrogen, oxygen and water vapour are 0.07321, 1.10359 and 0.625. These are the numbers from the actual experiments performed by Avogadro, nearly two hundred years ago. The ability to make such



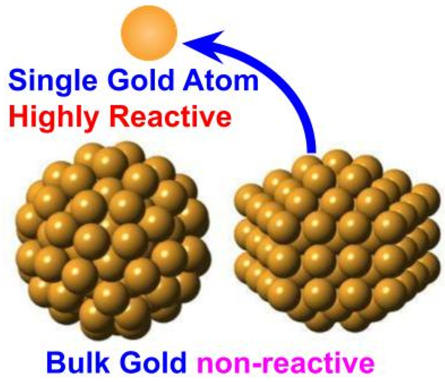
precise experiments in that era was solely responsible for Europeans dominating modern science. Since 0.625 equals 1.10359/2 added to 0.07321, it became clear that the smallest particle in water vapour was formed by the combination of one smallest particle in hydrogen and half a smallest particle of oxygen.

If the reaction is between sulphur and oxygen, 32grams of sulphur would be needed for 32 grams of oxygen. {Picture top left previous page} The easiest way to understand these results is to accept that the number of smallest particles in 32 grams of sulphur and 12 grams of carbon is the same. Therefore, the weight of the smallest particles in sulphur is 32/12 times the weight of the smallest particle in carbon. As the results of more and more chemical reactions are combined, we will realize that there are 94 “elements” in nature and that the innumerable materials we see around us are formed by the combination of elements. Dalton named the smallest particles in elements “atoms”. He further said that the atoms of one element differ from that of another in their weight, that the chemical properties differ because of these differences in weight, that one element cannot be converted into another and that atoms are indivisible.

Since Dalton’s original work, there have been many changes in chemistry. Most importantly we found that dividing atoms is possible. We now know that atoms of all elements are formed by the combination of three subatomic particles called electrons, protons and neutrons. The chemical properties of elements are determined not by the weight of the atom but the number of electrons in it. Changing the number of neutrons in the atom changes its weight but not the chemical properties. The two forces of nature that permit stars to be stable, can also cause one element to change into another. By altering the atoms, scientists have discovered newer elements which are however stable only for a

short time. Adding these, we now know 104 elements rather than 94. Despite all these changes, even today, chemistry mostly uses Dalton’s ideas. In ordinary chemical reactions one element does not become another. It is no wonder that the ancient alchemists never succeeded in converting base metals into gold. The variety of nature we see around us is purely due to chemical reactions between the elements. Chemistry is mostly the study of bonding between elements.

At low temperatures, say below 200°C, only the elements, Helium, Neon, Argon, Krypton and Radon can exist in atomic form. Atoms of all other elements are always found as molecules, which are formed when atoms form bonds with other atoms. Gold is a good example to understand this. A piece of gold is very inert. It does not react with chemicals. This is because the atoms in the piece of gold are strongly bonded to each other. A single atom of gold is highly reactive. {Picture right} Isolating one atom is possible with modern laboratory facilities. Single atoms of all elements are almost equally reactive. So all atoms in the piece of gold are bonded to one another and the piece has to be seen as a "molecule" with millions of atoms. Atoms in Mercury, like in gold form strong metallic bonds with one another. Mercury is a metal but it is a liquid at room temperature. Gold which does not react with other chemicals dissolves very fast in Mercury.

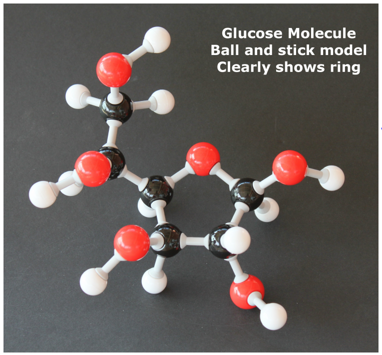


In a molecule of oxygen there are two atoms of oxygen bonded to one another. In a molecule of carbon dioxide two atoms of oxygen and one of carbon join together in a

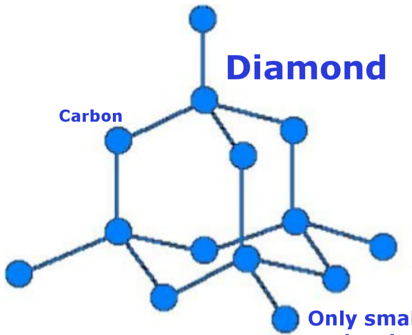
Water Vapour **Carbon Dioxide** **Methane**

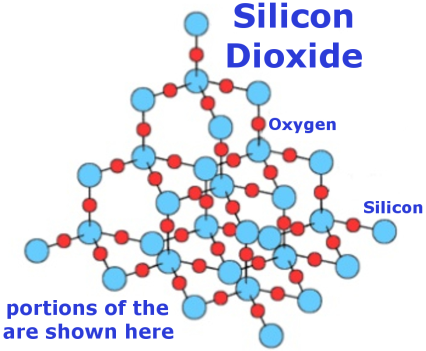
Space Filling Models

straight line. {Picture left} In a molecule of water on the other hand, the two hydrogen atoms attached to the oxygen form an angle of 105^{o}. In a molecule of methane, the four hydrogen atoms are at angles of 109^{o} to one another with the carbon atom at the center. In a molecule of glucose, a ring of atoms can be seen. {Picture below left} The bonds in these small molecules are rigid. The distances between atoms and the angles between bonds do not change much. In solids and liquids made of these small molecules, the bonds between molecules are much weaker than the bonds between atoms inside an individual molecule. The metallic bond between atoms of Gold or Mercury is different. The bond is not rigid. That is why metals can be beaten into thin sheets or drawn into wires.



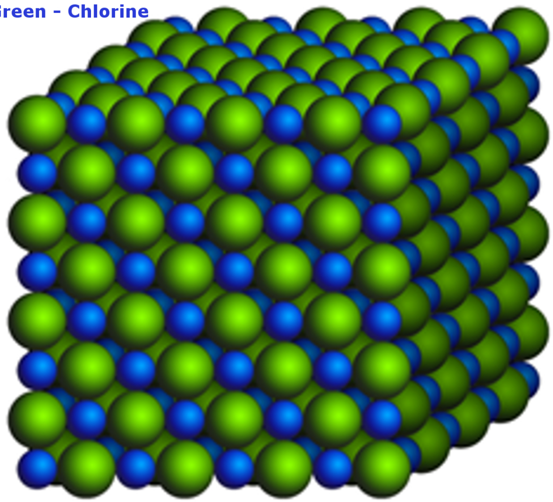
Metals are not the only molecules made by the bonding of an extremely large number of atoms. Diamond is another example. Pure diamond is made up of only carbon atoms. Each carbon atom bonds to four other carbon atoms around it with extremely rigid and strong bonds. {Picture top left opposite page} Just like in a small molecule of methane, the four bonds are at an angle of 109^{o} from one another. Because it has strong bonds in all directions, diamond is the strongest material known. Only a diamond can cut another diamond as the saying goes. Diamond cannot be beaten into a sheet like gold. Though a diamond is strong it easily shatters under





Only small portions of the molecules are shown here

Blue - Sodium
Green - Chlorine

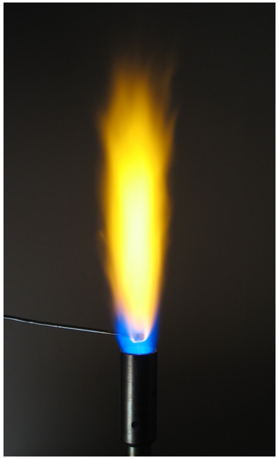


a hammer blow. Another mineral similar to diamond is quartz. In quartz, around one silicon atom, there are four other silicon atoms but between each pair of silicon atoms there is one oxygen atom. {Picture left top} The oxygen atom is bonded only to two silicon atoms and thus can move more easily than the carbon atoms in diamond. So quartz is not as strong as diamond. Also, the oxygen atoms can move slightly at extremely high temperatures, without the bonds being broken. Because of this, movement, quartz becomes soft at about 1700^{0}C. Diamond on the other hand can never becomes soft, but it burns in air at 900^{o}C.

Extremely large numbers of atoms form another very familiar molecule, a crystal of table salt used in cooking. It is made of sodium and chlorine atoms which are in the form of ions. {Picture left bottom} Each of the Sodium atoms gives one of its electrons and each Chlorine atom accepts that

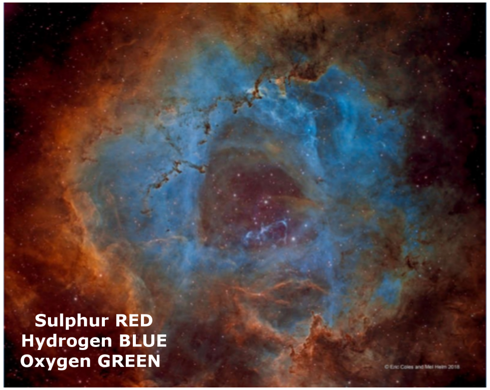
electron. The electrical forces of attraction between these “ions" results in the formation of a crystal. {Picture bottom left previous page} As shown in the picture, each chlorine “anion” is surrounded by sodium “cations” and each sodium cation is surrounded by chlorine anions. The whole of the crystal is a molecule. The bonds are caused by electrical attraction. The salt crystal, unlike a metal cannot be beaten into a thin sheet.

Another type of large molecules are in the shape of long strings. Just like in small molecules, the bonds along the string are rigid and strong. But just like a piece of thread, the “polymer” folds on itself. It can form a tangle and even form weak bonds at some places. Among familiar polymeric materials are rubber, nylon etc. which are artificially created and cotton, silk, spider’s web etc. which are natural. Long polymer molecules are the most important part of all living bodies.



Newton’s law of gravity is universal. There are no exceptions. All bodies with mass will attract each other. Similarly, the properties of atoms are universal. The properties of the atoms will not change irrespective of whether the atoms are in air, water, human bodies or even in stars. People claiming supernatural powers and their followers completely forget about this universality. The powers to control atoms, against the laws of modern science, are purely fictional.

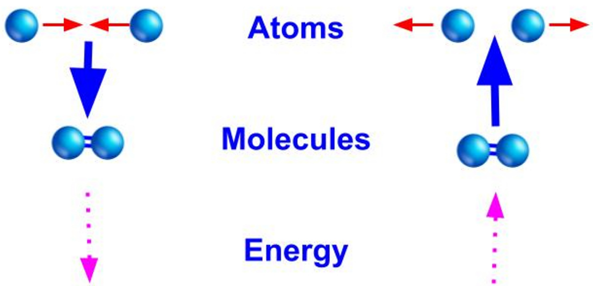
How do we know what atoms exist in a distant star? How do we know that the properties of the bonds formed betweens atoms are universal? Surprisingly, this can be verified using very simple experiments. If we introduce a small quantity of table salt, sodium chloride into the pale

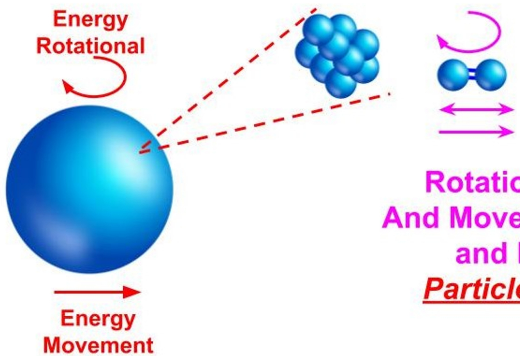


blue flame of natural gas, a particular yellow color is seen. {Picture left bottom previous page} The same color is seen whenever any other chemical containing sodium is put in the flame. The "color" seen can be measured very precisely in the laboratory. The specific yellow color shows the presence of sodium. When the same color is found in star light, a scientist is confident that sodium is present in the star. What was later named as the element Helium was detected by its specific color in sunlight even before it was discovered on the earth. Picture on left shows presence of sulphur, oxygen and hydrogen in star light. Just like atoms, bonds between atoms also show distinct color. But the human eye is not capable of seeing that color. Several carbon compounds have been identified in the clouds of dust surrounding distant stars {Picture right} Carbon dioxide on the planet Venus and methane on Titan, a satellite of the planet Saturn have also been similarly identified.

Why do atoms form bonds? Why does water flow down hill? The reason in both cases is the same. As discussed earlier, work has to be done against gravity to lift water to a hight and this work done

becomes potential energy of water. This energy is lost to the surroundings when the water flows down. Similarly, whenever a bond forms between two atoms, a quantity of energy is released. {Picture right} Atoms also have potential energy. But to break a bond between atoms, work has to be done not against gravity but against the force of electrical attraction. When the bond forms this potential energy is released. If the water is at a height but between two hills, the water does not flow down unless some further work is done to lift the water over the barrier. Similarly, there can be a barrier to the formation of a bond between atoms. The energy required to overcome the barrier may even be much larger than the energy released when the bond is formed. When a bond is formed between two atoms, the energy is released as a single particle. Energy is always in the form of small particles. Just as atoms in the matter surrounding us are not visible to our senses, we cannot sense individual particles of energy. We can only sense the change in kinetic energy of large bodies. Kinetic energy is required for large bodies to move, rotate or vibrate. {Picture left} One particle of energy causes the movement,





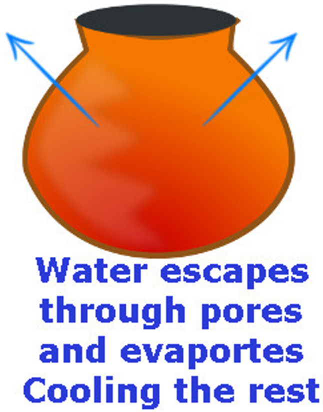
Rotation, Vibration
And Movement of Atoms
and Molecules
Particles of Energy

rotation of vibration of atoms, electrons or atomic bonds to change. This can be detected by highly accurate measurements in the laboratory but cannot be sensed by humans.

Some bonds between atoms are much stronger than others. For example in a liquid made of small molecules, the bonds inside the molecule are stronger than the bonds between molecules. Would not more particles of energy be required to break such strong bonds? Would not more particles of energy be released when they are formed?

Chemical bonds between atoms are formed by electrons. An electron is much smaller than even an atom. So the chance that more than one particle of energy can reach this extremely small region of space at the same time is very small. In certain laboratory experiments, using powerful lasers such effects can be very occasionally noticed.

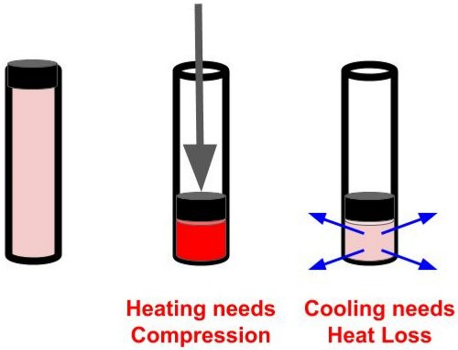
Some particles of energy have much more energy than others. We saw that different elements when introduced into a flame give out different colors. The colour determines the energy of the particle of energy. In physics the color is defined by the length of the wave. To claim that a particle of energy can have a wavelength is against human perception and logic. But such a description is necessary in quantum mechanics. To make it even more confusing, in quantum mechanics, you cannot know the path along which any particle has travelled. However, the experimental results agree with calculations made using quantum mechanics, in some cases, to the tenth decimal place. So scientists have agreed to use quantum theory. We first considered that any body is made of small particles and later identified them as atoms joined together as molecules. In quantum mechanics, the particles of energy have many names, photons, rotons, phonons etc. It is not possible to simplify all this and so in this book we continue to use the word particles of energy. It is most important

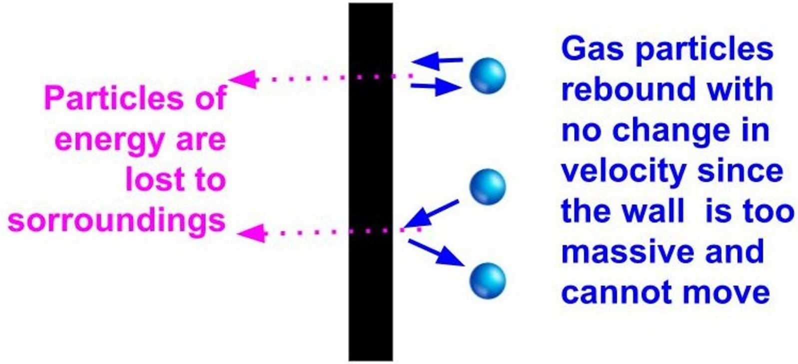


to understand that in physics, the theory need not describe nature in words that are understandable. The theory has to help us calculate experimental results. This is the basic difference between modern science and the mere wishful thinking of ancestors.

Let us now describe a few very simple processes as changes in atoms and molecules. Water is boiling in a pot. We know that water starts boiling at 100^{o}C and that some heat is required to turn one liter of water at that temperature into steam. This is called the latent heat of vaporization. If we look at the molecules of water, the latent heat is the energy required to break the bonds between molecules in the one liter of water. Even when water temperature is less than 100^{o}C, water evaporates from the surface.{Picture left above} All the molecules do not have the same speed. Some molecules gain speed due to collisions with the others as seen earlier in gases. These break the bonds with other molecules and become water vapour. As they carry away energy in the form of higher than average kinetic energy, the remaining water cools.

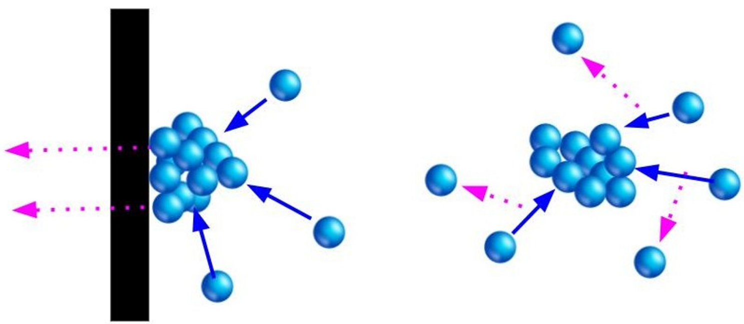
Everyone who pumped air into a cycle tyre knows that the bottom of the pump gets heated. {Picture top left opposite page} When the volume of air in the cylinder is reduced by





pushing the piston against gas pressure, work is done. This increases the speed of gas molecules and this energy heats the cylinder and this slowly heats the outside air.

A big question. As discussed earlier, pressure in the cylinder is due to the momentum given by the collision of the molecules in the gas with the wall. The weight of the molecules is very small. The cylinder is much heavier. So, according to the law of conservation of momentum, the gas molecule should reverse direction without loss of speed, since the cylinder cannot move. So how is the heat produced and lost to the surroundings? We will only get the correct answer when part played by the particles of energy is recognized. The atoms and molecules in the wall of the cylinder vibrate. {Picture right above} The momentum of the energy particles of the vibration has to be included in the conservation of momentum. These vibrational energy particles also transfer the heat from the hot cylinder to the surrounding air. What if the gas becomes liquid at higher pressures? For this, first a small number of molecules join to become a micro droplet of liquid. This should lose the excess energy rapidly. Otherwise the droplet would again become vapour. This is easier if



the droplet forms on the cylinder wall. {Picture left} This is the reason dew droplets form on metal surfaces of cars during winter. Rain droplets form first on the small dust particles. When the droplet becomes larger, gravity causes to fall as rain drops.

The above description of the role of energy particles helps us to dismiss silly fears about the radiation from cell phones, microwave ovens and power transmission towers. Some points are very important and worth repeating. Only one particle of energy is absorbed at one time by an electron or atom. A large number of particles of energy cannot collectively give energy to a single atom or bond. The energy content of a single particle of energy decreases proportionately with the wavelength. Wavelength of X rays is about one tenth of a nanometer. The wavelength of microwaves in the oven is between 100 to 300 million nanometers. That means the energy of one particle in X rays is more than the combined energy of 3 billion particles of energy in a microwave oven. The wavelength of radio waves in cell phones are in the range of 10 meters, much longer than even the microwave.

All these fears about radiation have been triggered by a name in history. In 1896 Henry Becquerel discovered a new type of rays that were passing through all materials except thick lead. Radio transmission was discovered a few years earlier and radio waves also travel long distances in the atmosphere. Because of this accidental similarity, Becquerel

named the newly discovered rays, radio activity. From this came the fear that anything named radiation is dangerous. Many people refuse to accept that only energy particles with short wavelengths and high energy are dangerous.

Only radiation starting with ultra violet, that is to say wavelength less than 400 nanometers can begin to damage health. When a particle with excess energy disrupts a bond between atoms, the excess energy is given to the atoms. These then start disrupting other atoms and bonds in the neighbourhood. That is why precautions are necessary. There is no basis for the fears regarding radiation in cell phones, microwave ovens and power line towers.

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